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Water quality and health risk of public drinking water sources: a study of filtration plants installed in Rawalpindi and Islamabad, Pakistan

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ABSTRACT

Safe drinking water is the basic human right in any region of the world. With increasing population and anthropogenic activities, this basic entity is in danger. This situation is more worsen in developing countries where no monitoring and maintenance is being followed. The present study is based on the monitoring of filtration plants for drinking water in two populated cities of Pakistan to determine the water quality status. Drinking water samples from Rawalpindi (n = 53) and Islamabad (n = 32) were taken from filtration plants installed by Capital Development Authority (CDA) in Islamabad and Water and Sanitation Agency (WASA) in Rawalpindi Pakistan. Physio-chemical parameters metals were analyzed using the standard procedures and multivariate indices and health risks were calculated. The results showed that electrical conductivity, alkalinity, and arsenic were above the permissible limit of the World Health Organization. 32 out of 53 samples in Rawalpindi while 26 out of 32 samples in Islamabad were found under poor water quality category with water quality index (WQI) > 100. Hazard index of arsenic was found <1 in adults (9.80E+01 and 7.03E+01) and children (1.48E+02 and 1.06E+02) at Rawalpindi and Islamabad respectively. Especially, children are found more prone to health hazards. Microbiological (bacteriological) components were incorporated to check the health risks due to water contamination. Proper management should be taken for the sustainability of limited underground water. This study will provide basic information regarding water quality in two large cities in a developing country of Pakistan.

Keywords: Health risk; Rawalpindi and Islamabad; Water quality

1. Introduction

The importance of water for human health, economic development, and population growth can never be ignored [1]. Safe water is one of the basic human needs and is considered as an unquestionable factor for good health. Organic compounds before not known to be substantial in freshwater, in relation to concentration and distribution, are now being more widely noticed as analytical techniques improved [2]. These compounds, which have the possible to cause suspected or known adverse for human health

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and ecologically, are often together referred to as emerging contaminants [3]. Heavy metals and organic and inorganic chemicals are found in surplus in some regions of the world [4]. Pure and contaminated water determines population health [5] so the importance of clean water cannot be ignored therefore there is a rising concern over water pollution in recent times. Water quality of both surface and groundwater has been identified as one of the main issues in Pakistan, due to four major water quality tribulations such as bacteriological, arsenic, nitrate and fluoride contamination [6]. Safe water concerns have been highlighted intensely in the last few years and many water purification technologies have been introduced in the country to remove undesirable chemicals, materials, and biological contaminants from raw water. However; the water that is reasonably contaminant-free (and safe) one moment can become dangerously contaminated the next because of accident, neglect, or some natural event. Access to safe drinking water in Pakistan is a critical health issue that will increase with projected population growth [7]. The demand for water has increased manifolds due to the ever-increasing population, urbanization, large scale cultivation and industrialization [1]. On the other hand, the quality of water resources of the country has been deteriorated by the impacts of the various human, industrial and agricultural activities [8]. Contaminants such as microorganisms, chemicals, toxic substances, industrial wastes or wastewater in higher concentrations make water unfit for drinking [9]. Such contaminants cause acute or chronic health effects such as circulatory system problems, skin diseases, kidney damage, bone damage, gastrointestinal stress, blue baby syndrome, increased risk of cancer and nervous system disorders, etc [10,11]. Without addressing the prevailing water quality issues, public health status cannot be improved [12]. As one indication of the magnitude of the problem, it is estimated that many children die every year due to diarrheal diseases alone [13]. The population growth rate is also very important as the world urban population is increasing every year [14]. This study is important because Islamabad is the capital city of Pakistan and Rawalpindi is one of the populous city urbanization has positive impact on the country economy and social development [15–17], but contrary to this, rapid and unplanned urbanization has a different kind of problems in developing countries such as traffic, air pollution and pressures on water resources [18]. The potential for urbanization processes to have an impact on the underlying groundwater is a function of its susceptibility to the consequences of excessive abstraction. Groundwater resources are decreasing with increasing demands for irrigation and urban utilization. There is clear evidence that underground water use is a higher average recharge in Pakistan [19]. On the other hand, the rapid growth of both Islamabad and Rawalpindi has made ever-increasing demands on water resources, natural resources and caused adverse effects on the environment. This paper presented the results that aimed at (1) to evaluate the chemical quality of drinking water being supplied to general public by water filtration plants in Islamabad and Rawalpindi, (2) to highlight the need of further improvements in water treatment process and water quality monitoring on routine basis, and (3) To safeguard the public health against contaminated drinking water.

2. Material and method

2.1. Study area

This study is conducted in two cities of Pakistan, Islamabad, and Rawalpindi, Islamabad is located at 33° 29′ 26.7″N and 72° 48′ 42.08″E to 33° 48′ 1.34″N and 73° 22′ 48.51″ at the northern edge of the Pothohar Plateau and the foot of the Margalla Hills having elevation of 540 m (1,770 ft.). The climate of Islamabad is humid subtropical with five seasons: Heavy rainfall is observed in July with the possibility of cloudbursts and flooding. January is usually the coldest month. The inhabitants of Islamabad depend on both surface and groundwater as their domestic water source. Rawalpindi, commonly known as Pindi, is a city in the Punjab province of Pakistan. Rawalpindi is adjacent to Pakistan's capital of Islamabad, and the two are jointly known as the "twin cities" on account of strong social and economic links between the cities. Rawalpindi is the fourth-largest city in Pakistan by population, while the larger Islamabad Rawalpindi metropolitan area is the country's third-largest metropolitan area. Map of the study area and sampling sites is shown in Fig. 1.

2.2. Sample collection and analysis

The government of Pakistan controlled authorized like Water and Sanitation Agency (WASA) and Capital Development Authority (CDA) installed a number of water plants in Rawalpindi and Islamabad. A total number of 33 water filtration plants were monitored at Islamabad and 53 at Rawalpindi with the collaboration of the Pakistan Council of Research in Water Resources (PCRWR) to determine the water quality analysis water quality assessment, health risk assessment and some statistical analysis was performed. A total number of 86 water samples were collected from water filtration plants installed in both cities and water quality analysis was performed as per the American Public Health Association (APHA) [20].

2.2.1. Analytical procedures

The pH was measured by pH meter (Hanna Instrument, Model 8519, Italy), electrical conductivity (EC) and total dissolved solids (TDS) were measured EC meter (Hach-44600-00, USA), calcium from ethylenediamine tetraacetic acid method, magnesium from gravimetric method, alkalinity, and hardness from titrimetric method, chloride from APHA 4110B, sodium and potassium from flame photometer, Bicarbonates from titration method, nitrates from diazotization method while sulphate from 4500-SO_4^{-2} turbidimetric method. Arsenic and iron from the atomic absorption spectrophotometer. All the methods were adopted from APHA [20].

2.3. Water quality assessment

Water quality index (WQI) was firstly proposed by Horton [21], later used by numerous scientists to determine the pollution quantitatively. Total 9 parameters (pH, Alkalinity, Cl, Na, NO_3, SO_4, As, TC, FC) were selected to calculate WQI (as per availability of their assigned weight from literature) by the following formula:

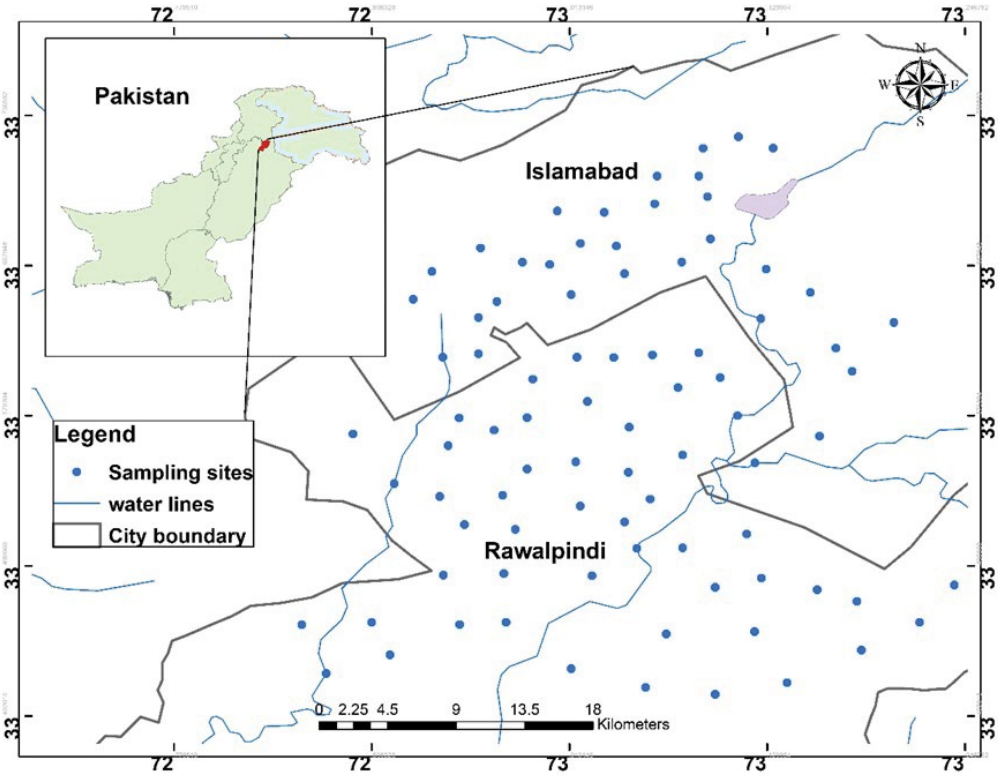

Fig. 1. Geographical location of the study area and sampling sites.

$$Q_i = \left[\frac{C_i}{S_i}\right] \times 100 \tag{1}$$

$$SI_i = RW \times Q_i \tag{2}$$

$$WQI = \sum_{i=1}^{n} SI_i \tag{3}$$

where RW is the relative weight, by dividing assigned weight with the sum of assigned weights for all parameters, Q_i is a quality index calculated by dividing the concentration of pollutants with standards value and multiplying with 100 in Eq. (1).

Classification of WQI, described by Ramakrishnaiah et al. [22] is as follow:

>50 = Excellent, 50–100 = Good, 100–200 = Poor, 200–300 = Very poor, <300 = Unsuitable.

2.4. Health risk assessment

Heavy metals enter into the human body through three exposure routes via ingestion, dermal and inhalation [23], the major exposure is inhalation. In the present study two metals (As and Fe) were selected and irrespective of gender, adult and children were grouped as two subjects. Average daily dose (ADD) (mg/kg/d) of water intake was calculated by using the following formula by the United States Environmental Protection Agency (USEPA) [24]:

$$ADD_i = C_i \times \frac{IR}{BW} \tag{4}$$

where C is the ith concentration (mg/L) of metal, IR intake rate (2 L/d in adults and 0.63 in children), BW is body weight (72 kg for adults and 15 kg for children) as described by Sohail et al. [25].

Based on total contents, hazard quotient (HQ) was computed as:

$$HQ_i = \frac{ADD_i}{RfD} \tag{5}$$

where RfD is the reference dose given by USEPA. For As it is 0.0003 [26] and for Fe it is 0.7 [25].

Hazard index (HI) is the sum of total HQ in a sample and it was calculated by using the following formula:

$$HI = \sum HQ_i \tag{6}$$

The HQ > 1 will be considered as chronic risks is more than the threshold level and its probability of occurrence [27–29].

2.5. Statistical analysis

Statistical analysis was conducted including the coefficient of correlation, regression, principal component analysis (PCA) to determine the behavior of different parameters by using MS Excel 2013 and Origin (Version 9). Piper diagram was prepared through Aqua-Chem (version 2010.1) to interpret hydrochemical facies.

3. Results and discussion

3.1. Water quality assessment

Analytical results of all the filtration plants (Islamabad and Rawalpindi) were compared with the World Health Organization (WHO) and Pakistan Standards and Quality Control Authority permissible limits for drinking water. Water samples of all the filtration plants were found safe with respect to physicochemical water quality parameters, but out of a total of 32 monitored filtration plants of Islamabad, 9 plants have shown the prevalence of bacteriological contamination in the water being supplied (Table 1 and S1). Out of a total of 53 monitored filtration plants of Rawalpindi, 38 filtration plants were found to provide unsafe drinking water due to prevalence of bacteriological contamination and 10 filtration plants are found to be unsafe with respect to excessive nitrate levels than the permissible level, 08 plants have shown chemical and bacteriological contamination simultaneously. Overall, 40 filtration plants out of 53 monitored plants are found to provide unsafe drinking water (Table 1 and S1).

Details of water quality parameters and concentration in filtration plants both in Islamabad and Rawalpindi can be seen in Table 2. The average concentration of EC (779 ± 223 and 641.3 ± 171), alkalinity (320 ± 69 and 256 ± 86) and arsenic (1.05 ± 0.56 and 0.75 ± 0.3) in a sample collected from Rawalpindi and Islamabad respectively were found higher than the permissible limits of WHO [30]. The other parameters (pH, TDS, Ca, Mg, Hardness, HCO_3, Cl, Na, K, NO_3, SO_4, Fe) were found within the tolerable range. The range of parameters found higher at Rawalpindi water samples than Islamabad. PCRWR [31] conducted a study in large cities of Pakistan and found more than 70% of samples were polluted with different and 100% were polluted with fecal contamination. The major factor of contamination is overpopulation and anthropogenic activities in Pakistan

Table 1
Bacteriological contamination (total coliforms and *E-coli*)

Sr. #	Filtration plant	Results		Sr. #	Filtration plant	Results	
		Total coliforms (MPN/100 ml)	*E-coli* (+ve/–ve)			Total coliforms (MPN/100 ml)	*E-coli* (+ve/–ve)
				Islamabad			
1	CDA-2	02	–ve	6	CDA-20	33	–ve
2	CDA-8	08	+ve	7	CDA-22	02	–ve
3	CDA-14	14	–ve	8	CDA-23	14	+ve
4	CDA-15	17	–ve	9	CDA-30	08	–ve
5	CDA-19	04	–ve				
				Rawalpindi			
1	WASA-1	31.8	9.6	20	WASA-30	3.1	–ve
2	WASA-2	16.0	–ve	21	WASA-32	2.0	2.0
3	WASA-3	1.0	–ve	22	WASA-33	47.7	7.5
4	WASA-4	2.0	1.0	23	WASA-34	52.0	5.2
5	WASA-6	2.0	–ve	24	WASA-35	2419.6	88.9
6	WASA-10	26.2	13.2	25	WASA-36	85.0	2.0
7	WASA-13	410.6	–ve	26	WASA-37	435.2	8.5
8	WASA-14	2.0	1.0	27	WASA-38	8.6	3.1
9	WASA-15	24.6	–ve	28	WASA-39	2419.6	410.6
10	WASA-17	117.2	4.1	29	WASA-41	3.1	–ve
11	WASA-18	2.0	–ve	30	WASA-42	4.1	–ve
12	WASA-19	1.0	–ve	31	WASA-43	3.1	–ve
13	WASA-20	15.6	–ve	32	WASA-45	53.8	–ve
14	WASA-21	80.9	–ve	33	WASA-46	261.3	52.9
15	WASA-23	4.1	–ve	34	WASA-47	1732.9	70.8
16	WASA-24	36.4	–ve	35	WASA-48	2419.6	3.1
17	WASA-25	4.1	–ve	36	WASA-50	178.5	–ve
18	WASA-28	1.0	–ve	37	WASA-51	>2419.6	235.9
19	WASA-29	24.6	–ve	38	WASA-53	1119.9	179.3

MPN: Most probable number.

Table 2
Concentrations of water parameters in Rawalpindi and Islamabad samples

Sr #	Parameters	Rawalpindi (n = 53)		Islamabad (n = 32)		WHO permissible limit (2011)
		Mean ± SD	Range	Mean ± SD	Range	
1	pH	7.31 ± 0.24	6.89–7.87	7.20 ± 0.22	6.85–7.82	6.5–8.5
2	EC (ms)	779 ± 223	296–1474	641.3 ± 171	384–980	250
3	TDS (mg/L)	439 ± 139	163–884	354 ± 93	211–539	1,000
4	Ca (mg/L)	85 ± 17.6	40–128	70.93 ± 17.1	40–96	75
5	Mg (mg/L)	27.1 ± 12.7	0–61	23 ± 9.1	7–44	–
6	Hardness (mg/L)	325 ± 74.2	140–515	272 ± 57.7	170–360	–
7	Alkalinity (mg/L)	320 ± 69	115–455	256 ± 86	30–360	120
8	HCO_3 (mg/L)	320 ± 69.5	115–455	266 ± 77.6	110–360	–
9	Cl (mg/L)	30.9 ± 14.7	9–74	15.2 ± 7.74	5–42	250
10	Na (mg/L)	42.2 ± 25.7	9–140	23.90 ± 13.1	5–53	–
11	K (mg/L)	1.72 ± 0.56	1–3.5	1.38 ± 0.48	0.4–2.5	–
12	NO_3 (mg/L)	5.21 ± 4.58	0.5–22	3.12 ± 2.35	1–10	–
13	SO_4 (mg/L)	47 ± 34.8	11–170	40 ± 16.9	20–85	250
14	As (mg/L)	1.05 ± 0.56	0.26–1.8	0.75 ± 0.3	0.06–1.63	0.01
15	Fe (mg/L)	0.44 ± 0.43	0.03–1.09	0.56 ± 0.44	0.04–1.09	–

[32]. Arsenic is mobilized in aquifer and geohydrological is the major reason for the higher level of its pollution which already reported by many authors [33]. Out of 32 sites in Islamabad, only one site was suitable for drinking water purposes which were Pak secretariat P Block. 5 sites were categorized in poor water quality with 100–200 WQI value which was G 9/3, G 7/4, G 6/1-2, G 11/3 and I-10/1 Islamabad. 10 sites fall under very poor water quality and 16 came under unsuitable for drinking purpose. Whereas, out of 50 samples in Rawalpindi, more than 32 samples have WQI > 100 (Fig. 2) showing poor water quality. The four sites Satellite town, 6th Road, A-Block, Dhoke Ratta and Near DSP Office Rawal Town (WASA-12, WASA-17, WASA-22, WASA-53) have WQI > 300 showing unsuitable drinking water. The location and value of WQI have been given in supplementary information as Table S1. This indicated that water quality deteriorated with population expansion. Al-Mutairi et al. [34] determined the WQI of surface water and found that 31.9% were classified as excellent and this percentage was decreased to 1.5% on next year due to contamination. Alobaidy et al. [35] also found that with time WQI abruptly decreased to poor WQI due to anthropogenic activities and population expansion. So, the water quality of Islamabad also declined due to urbanization within 20 years which ultimately put the bad impacts on residence health as well as on the ecosystem. Numerous other researchers [36] also found the WQI and found poor water quality in most of the region with over-population.

3.2. Health risk assessment

The values of HQ in arsenic was found <1 in water samples both in adult (9.80E+01 and 7.03E+01) and children (1.48E+02 and 1.06E+02) in Rawalpindi and Islamabad respectively. It indicated that arsenic in both locations is more than the threshold level and hazardous for adults and children. Fe found within the threshold limit (HQ < 1) in both adults and children. HI found more in children (1.48E+02 and 1.06E+02) than adults (9.80E+01 and 7.03E+01) Rawalpindi and Islamabad respectively (Table 3). However, the overall values found the hazard occurs and the population is at high risk. HQ > 1 in children shown that in the comparable conditions, children are extra vulnerable than adults [36,29] determined the HQ in local inhabitants and found that the HQ for different metals designated no risk to the local population.

3.3. Relationship and behavior of major ions

A realistic relationship between two parameters for water quality description can be described by mathematical models. This analysis provides a mechanism for forecasting and provides a means to establish the nature of the relationship between the variables. Pearson's correlation analysis was performed for multivariate parameters, a strong correlation among different parameters of Rawalpindi city can be seen highlighted numbers (Table 4). A strong positive correlation exists among EC and TDS and shows a good positive correlation with Ca, Mg, Hard, Alkalinity, HCO_3, Cl, Na, NO_3, SO_4 and are also the more significant correlation pairs. TDS is a sum of all the cations and anions in water. The relationship of TDS with cations (Fig. 3a) shows a strong positive correlation with Na^+, Ca^{2+}, and Mg^{2+} with an R^2 value of 0.405, 0.5292, and 0.818 respectively. Also, a good positive correlation exists between TDS and anions, including Cl^-, HCO_3^-, and SO_4^{2-} with 0.7617, 0.7122, and 0.6536 R^2 value (Fig. 3b). The result illustrates that As shows a positive relationship with Fe (R^2 = 0.61) (Fig. 5a) and from Pearson's correlation (0.79) (Table 4). This suggests that Fe could be the cause of As release in groundwater. There is also a strong positive correlation that exists among EC and TDS in Islamabad City and shows a good positive correlation with Ca, Mg, Hard, Alkalinity, HCO_3, Cl, Na, NO_3, SO_4 and are also the more significant correlation pairs. TDS is a sum of all the cations and

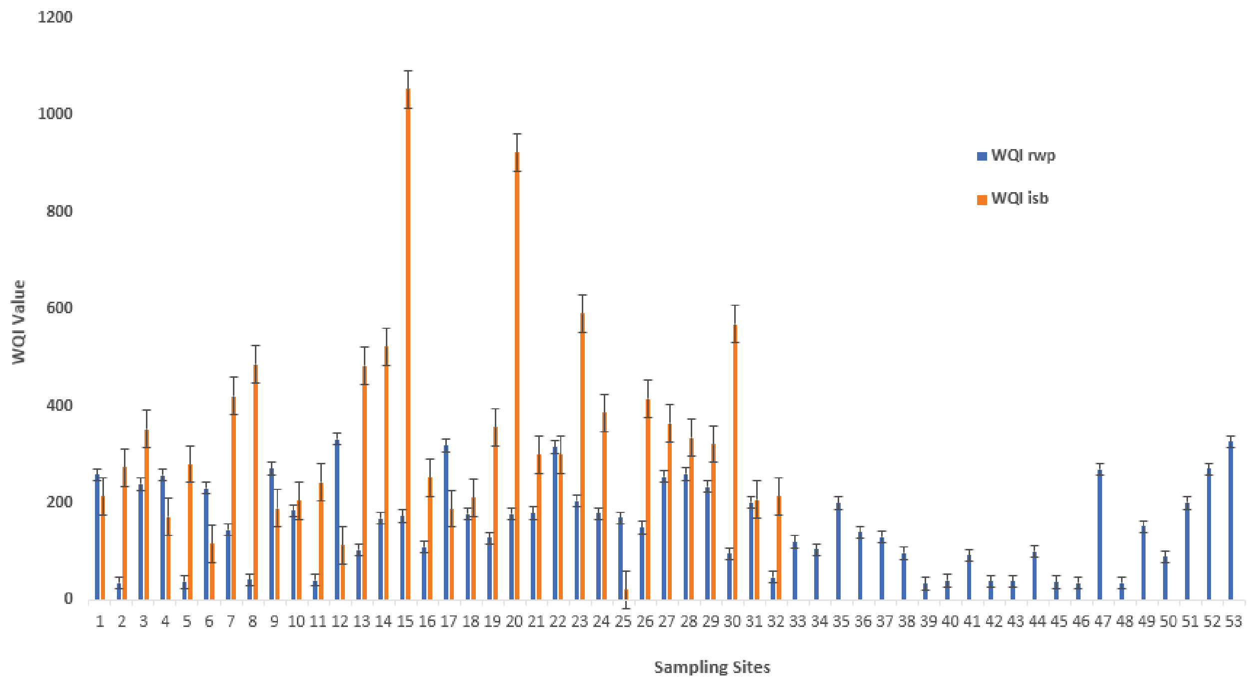

Fig. 2. WQI of selected sites in Islamabad and Rawalpindi.

Table 3
Health risk assessment of in children and adults by using filtration plant water

Locations	Hazard quotient (HQ)				Hazard index (HI)	
	As		Fe			
	Adult	Children	Adult	Children	Adult	Children
Rawalpindi	9.80E+01	1.48E+02	1.76E-02	2.66E-02	9.80E+01	1.48E+02
Islamabad	7.03E+01	1.06E+02	2.24E-02	3.38E-02	7.03E+01	1.06E+02

Table 4
Correlation coefficient of Rawalpindi sampling sites

	pH	EC	TDS	Ca	Mg	Hard	Alkalinity	HCO_3	Cl	Na	K	NO_3	SO_4	As	Fe
pH	1														
EC	–0.08	1.00													
TDS	–0.06	0.99	1.00												
Ca	0.01	0.75	0.73	1.00											
Mg	–0.12	0.65	0.64	0.16	1.00										
Hard	–0.07	0.92	0.90	0.72	0.80	1.00									
Alkalinity	–0.17	0.87	0.85	0.73	0.57	0.85	1.00								
HCO_3	–0.17	0.87	0.84	0.72	0.57	0.84	1.00	1.00							
Cl	–0.11	0.88	0.87	0.63	0.66	0.85	0.66	0.66	1.00						
Na	0.07	0.88	0.90	0.65	0.40	0.68	0.70	0.70	0.73	1.00					
K	0.02	–0.26	–0.24	–0.41	–0.08	–0.31	–0.44	–0.44	–0.08	–0.05	1.00				
NO_3	0.05	0.85	0.87	0.59	0.57	0.77	0.58	0.58	0.84	0.80	–0.15	1.00			
SO_4	0.13	0.78	0.81	0.47	0.50	0.64	0.42	0.42	0.73	0.79	–0.03	0.80	1.00		
As	0.06	0.09	0.10	0.09	0.04	0.07	0.13	0.14	0.07	0.18	–0.03	0.09	0.04	1.00	
Fe	0.08	0.06	0.06	0.07	0.05	0.07	0.17	0.18	0.02	0.11	–0.01	–0.08	–0.01	0.79	1.00

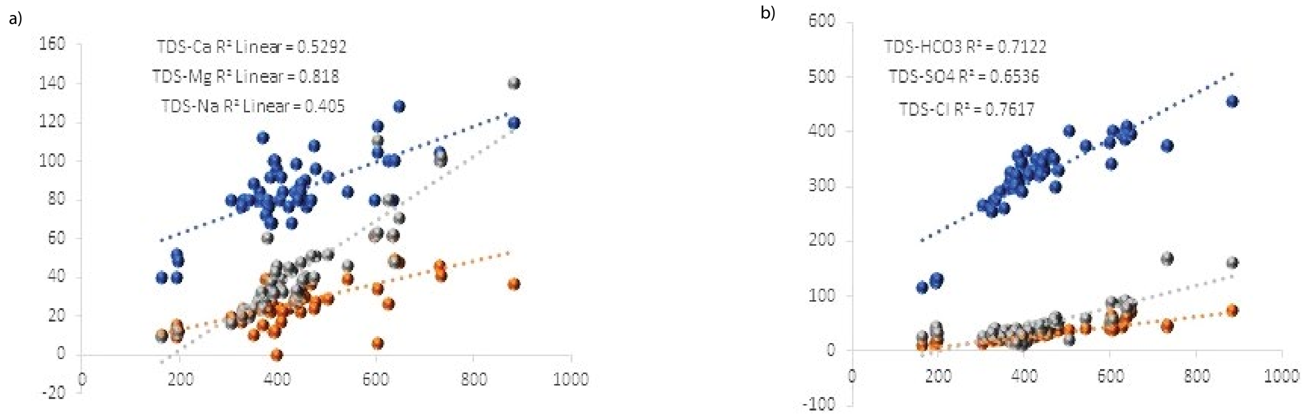

Fig. 3. Relationship of TDS with (a) cations and (b) anions of Rawalpindi water samples.

anions in water. The relationship of TDS with cations (Fig. 4a) shows a strong positive correlation with Na^+, Ca^{2+}, and Mg^{2+} with an R^2 value of 0.682, 0.527, and 0.260, respectively. Also, a good positive correlation exists between TDS and anions, including Cl^-, HCO_3^-, and weak with SO_4^{2-} with 0.526, 0.845, and 0.0004 R^2 value (Fig. 4b). The result illustrates that As shows a positive relationship with Fe (R^2 = 0.311) (Fig. 5b) and from Pearson's correlation (0.56) (Table 5).

3.4. Principle component analysis

PCA describes the percentage of the variance of different parameters from another. Fig. 6 shows the PCA for Rawalpindi and Islamabad water samples. The values of pH, K, Fe and As lies in PC1 with negative values in both locations showed the variance is high. Other parameters lie in PC2 with positive values and the variance between these parameters is low, they are closer and more dependent on each other. Percentage variance in sample of Rawalpindi site parameters were like 56%, 12.21%, 9.93%, 7.54%, 5.16%, 3.40%, 2.28%, 1.70%, 0.87%, 0.58%, 0.22%, 0.05%, 0.03%, 0.02% and 0.01% in pH, EC, TDS, Ca, Mg, hardness, alkalinity, HCO_3, Cl, Na, K, NO_3, SO_4, As and Fe respectively. The percentage variance in sample of Islamabad site parameters were like 54.6%, 14.66%, 8.01%, 6.80%, 4.90%, 3.27%, 2.75%, 1.77%, 1.36%, 1.11%, 0.54%, 0.16%, 0.04%, 0.02% and 0.01% in pH, EC, TDS, Ca, Mg, hardness, alkalinity, HCO_3, Cl, Na, K, NO_3, SO_4, As and Fe respectively.

3.5. Hydrochemical facies

Hydrochemical facies represent the overall situation of the interface of groundwater within a lithological. They are quite valuable in understanding the groundwater transition and pattern of its flow [37]. Piper diagram [38] shows a complete graphical picture of the hydrochemistry of samples and they are hydrochemical. To clarify the chemical differences, all the samples were plotted in the piper diagram (Figs. 7a and b). Most of the samples fall in Zone 1 ($CaHCO_3$ type). With respect to cations, groundwater samples fall in Zone A (Ca type) and Zone B (mixed type). With respect to anions, most of the samples fall in Zone E (HCO_3 type) and Zone B (mixed type), representing the dominance of carbonate weathering.

3.6. Population expansion

Pakistan facing rapid urbanization has witnessed a decrease in rural areas population from 61.4% in 2014 to 60.1% in 2016. However, the population in urban areas increased from 38.5% in 2014 to 40% in 2016. According to the Government of Pakistan Census 1998, the population of

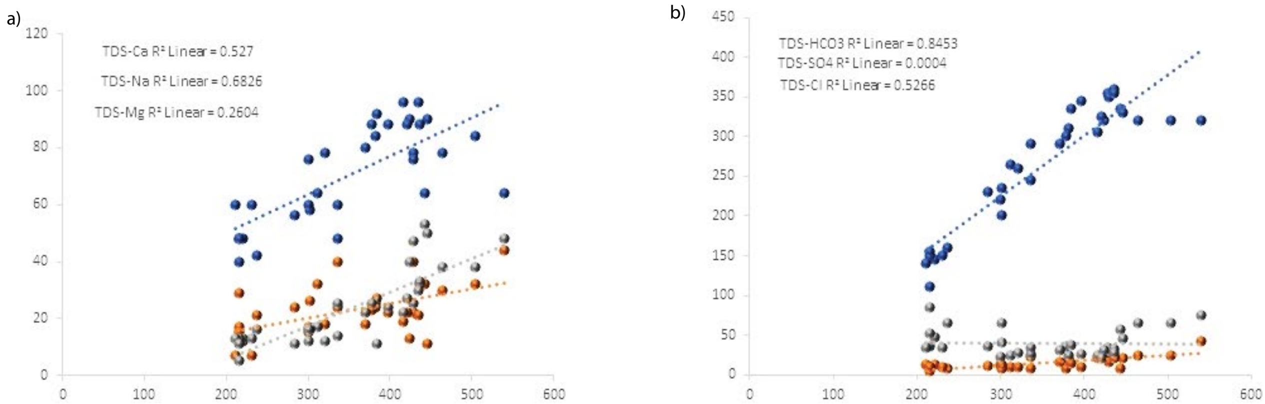

Fig. 4. Relationship of TDS with (a) cations and (b) anions of Islamabad water samples.

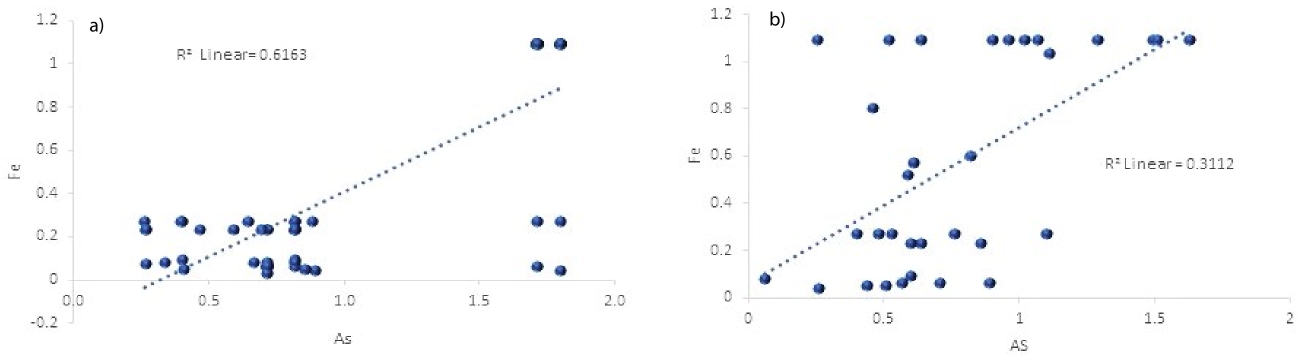

Fig. 5. Relationship of As and Fe in (a) Rawalpindi and (b) Islamabad water samples.

Table 5
Correlation coefficient of Islamabad sampling sites

	pH	EC	TDS	Ca	Mg	Hard	Alkalinity	HCO_3	Cl	Na	K	NO_3	SO_4	As	Fe
pH	1														
EC	–0.80	1.00													
TDS	–0.80	1.00	1.00												
Ca	–0.74	0.73	0.73	1.00											
Mg	–0.37	0.51	0.51	–0.01	1.00										
Hard	–0.82	0.88	0.88	0.76	0.64	1.00									
Alkalinity	–0.68	0.71	0.71	0.58	0.58	0.82	1.00								
HCO_3	–0.83	0.92	0.92	0.80	0.48	0.93	0.80	1.00							
Cl	–0.54	0.73	0.73	0.44	0.35	0.57	0.40	0.53	1.00						
Na	–0.56	0.82	0.83	0.46	0.29	0.53	0.40	0.69	0.60	1.00					
K	0.56	–0.54	–0.54	–0.64	–0.19	–0.62	–0.45	–0.59	–0.25	–0.21	1.00				
NO_3	–0.60	0.86	0.86	0.49	0.54	0.72	0.53	0.65	0.79	0.72	–0.28	1.00			
SO_4	0.21	–0.03	–0.02	–0.40	0.20	–0.18	–0.31	–0.32	0.06	0.12	0.12	0.26	1.00		
As	0.24	–0.21	–0.22	–0.27	–0.03	–0.23	–0.12	–0.30	–0.04	–0.22	0.09	–0.04	0.29	1.00	
Fe	0.38	–0.17	–0.18	–0.30	0.03	–0.23	–0.14	–0.32	–0.03	–0.13	0.17	0.02	0.34	0.56	1.00

*Filtration plants providing safe/unsafe drinking water.

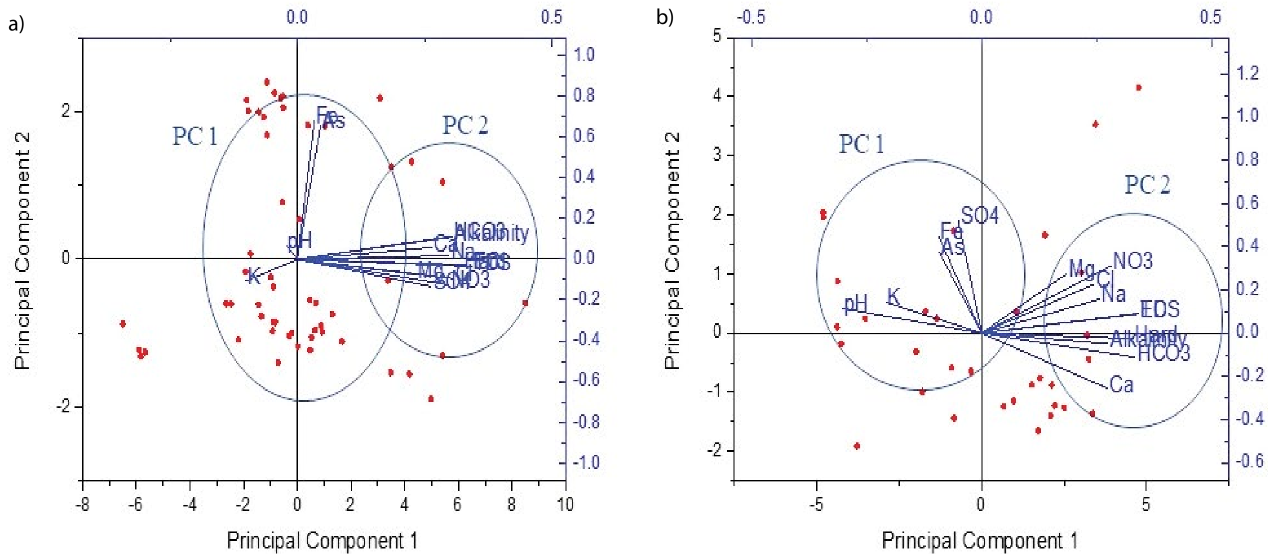

Fig. 6. Principle component analysis (PCA) in (a) Rawalpindi and (b) Islamabad water samples.

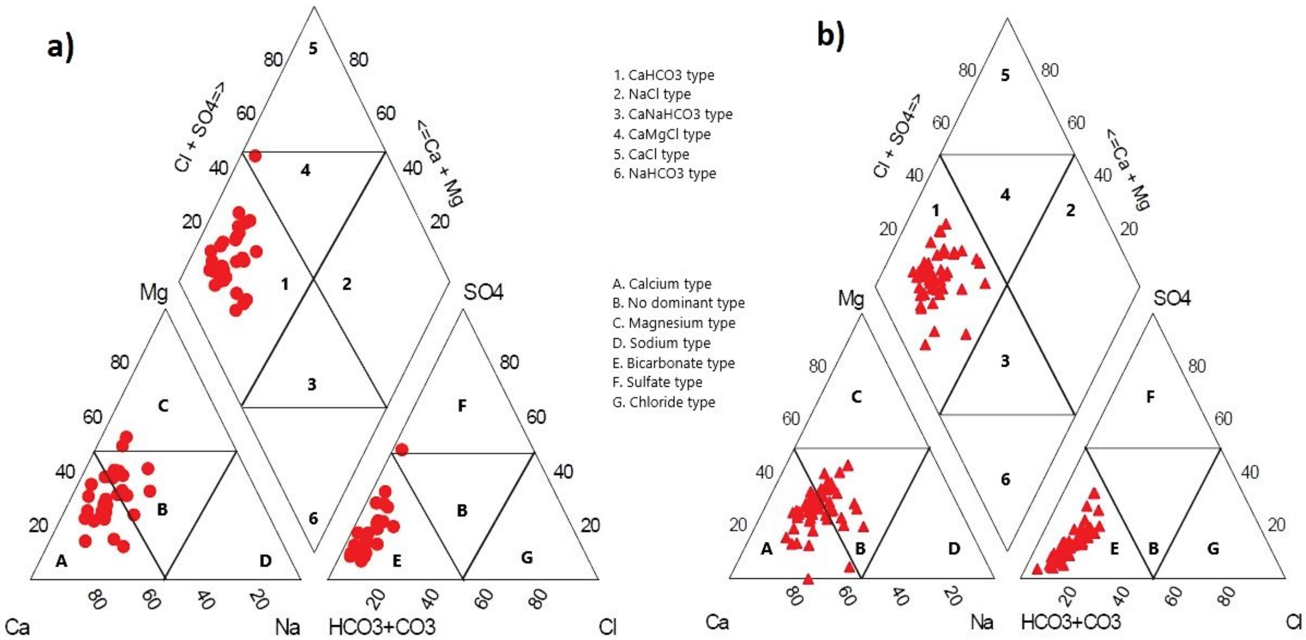

Fig. 7. Piper plot for hydrochemical facies classification in (a) Islamabad and (b) Rawalpindi water samples.

Islamabad city was 529,180, while in Rawalpindi city 1,409,768 and 2017 census, it increased to 1,014,825 in Islamabad and 2,098,231 in Rawalpindi Pakistan Bureau of Statistics [39,40]. All these statistics showed the population rate in this city is increasing and such a huge population has impacts on the ecosystem and at the same time water resources and its government responsibility to provide safe and clean water to citizens of these cities [41] (Fig. 8).

The twin cities, Islamabad and Rawalpindi, provides easy access to basic services like social equality and economic opportunities. Both these cities receive large-scale migrants from other rural areas around 1,063,576 people by the 1998 census, having a 3.46% growth rate in its urban population. The majority of migrants are from the areas whose rural livelihood has been disturbed by climate change and other disasters [42]. Most of the young people opt to move towards the capital for better education opportunities [43] devastating. Mostly, the twin cities receive a maximum number of migrants from Punjab and Khyber Pakhtunkhwa. Another

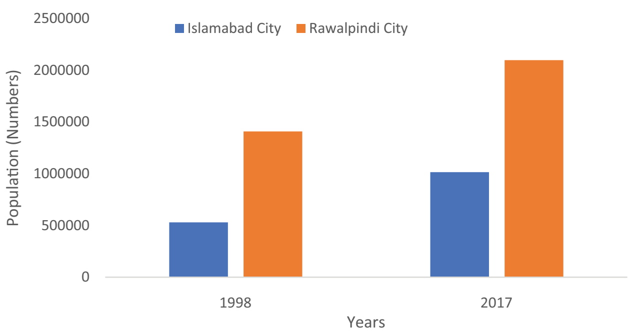

Fig. 8. Population rate in Islamabad city and Rawalpindi city. *Source*: Pakistan Bureau of Statistics (http://www.pbs.gov.pk) population census 1998 and 2017 Government of Pakistan,

significant reason for high urbanization is the international migrants from Afghanistan in huge numbers that moved

towards the twin cities as a consequence of the US invasion in 2001 and the Soviet invasion in 1990 [42]. In Islamabad–Rawalpindi, the living combinations of the local population and Afghan refugees have a complex dimension in unplanned settlements. It's very challenging for the local administration to provide their municipal necessities despite a considerable integration into the local economy and society [43].

4. Conclusion

Analytical results of all the filtration plants were compared with WHO permissible limits for Drinking water and EC, alkalinity, and arsenic were found higher. Arsenic is the major cause of water pollution in the study area. It also creates the risk of health hazard especially in children having values 1.48E+02 and 1.06E+02 in Rawalpindi and Islamabad respectively. The WQI was also calculated and found most of the water samples in poor condition. 60.38% of samples in Rawalpindi while 81.25% of samples in Islamabad were found unsafe for drinking. Out of the total 53 monitored filtration plants, 38 filtration plants are found to provide unsafe drinking water. Proper management should be taken for the sustainability of limited underground water. This study would provide a base for research related to urbanization and land change impacts information for policy formulation.

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Supplementary information

Table S1-A
Water quality index (WQI), chemical and microbiological results (Islamabad)

Sr. #	Sampling site	WQI value	Category	Chemical*	Sr. #	Sampling site	WQI value	Category	Chemical*
				Microbiological					Microbiological
1	CDA-1	214.1305	Very poor	Safe	17	CDA-17	187.7314	Poor	Safe
				Safe					Safe
2	CDA-2	273.0712	Very poor	Safe	18	CDA-18	210.7829	Very poor	Safe
				Unsafe					Safe
3	CDA-3	352.2362	Unsuitable	Safe	19	CDA-19	356.5382	Unsuitable	Safe
				Safe					Unsafe
4	CDA-4	171.2166	Poor	Safe	20	CDA-20	922.623	Unsuitable	Safe
				Safe					Unsafe
5	CDA-5	279.5818	Very poor	Safe	21	CDA-21	299.2981	Very poor	Safe
				Safe					Safe
6	CDA-6	116.155	Poor	Safe	22	CDA-22	299.9476	Very poor	Safe
				Safe					Unsafe
7	CDA-7	420.1747	Unsuitable	Safe	23	CDA-23	590.2722	Unsuitable	Safe
				Safe					Unsafe
8	CDA-8	486.1483	Unsuitable	Safe	24	CDA-24	385.7925	Unsuitable	Safe
				Unsafe					Safe
9	CDA-9	188.5548	Poor	Safe	25	CDA-25	21.10353	Excellent	Safe
				Safe					Safe
10	CDA-10	204.3481	Very poor	Safe	26	CDA-26	414.0186	Unsuitable	Safe
				Safe					Safe
11	CDA-11	242.7827	Very poor	Safe	27	CDA-27	363.6362	Unsuitable	Safe
				Safe					Safe
12	CDA-12	112.9947	Poor	Safe	28	CDA-28	333.8299	Unsuitable	Safe
				Safe					Safe
13	CDA-13	483.0809	Unsuitable	Safe	29	CDA-29	321.4103	Unsuitable	Safe
				Safe					Safe
14	CDA-14	522.6934	Unsuitable	Safe	30	CDA-30	568.3333	Unsuitable	Safe
				Unsafe					Unsafe
15	CDA-15	1,054.109	Unsuitable	Safe	31	CDA-31	206.2557	Very poor	Safe
				Unsafe					Safe
16	CDA-16	252.3167	Unsuitable	Safe	32	CDA-32	213.2237	Very poor	Safe
				Safe					Safe

Table S1-B
Water quality index (WQI), chemical and microbiological results (Rawalpindi)

Sr. #	Sampling site	WQI value	Category	Chemical* / Microbiological	Sr. #	Sampling site	WQI value	Category	Chemical* / Microbiological
1	WASA-1	257.8307	Very poor	Safe Unsafe	28	WASA-28	259.4187	Very poor	Unsafe Unsafe
2	WASA-2	34.02024	Excellent	Safe Unsafe	29	WASA-29	233.3648	Very poor	Unsafe Unsafe
3	WASA-3	238.6385	Very poor	Safe Unsafe	30	WASA-30	94.60472	Good	Safe Unsafe
4	WASA-4	257.3979	Very poor	Safe Unsafe	31	WASA-31	200.7466	Poor	Safe Safe
5	WASA-5	36.8914	Excellent	Safe Safe	32	WASA-32	46.04516	Excellent	Unsafe Unsafe
6	WASA-6	230.226	Very poor	Safe Unsafe	33	WASA-33	119.3314	Poor	Unsafe Unsafe
7	WASA-7	144.6681	Poor	Safe Safe	34	WASA-34	103.916	Poor	Unsafe Unsafe
8	WASA-8	41.29269	Excellent	Safe Safe	35	WASA-35	199.4284	Poor	Safe Unsafe
9	WASA-9	270.7801	Very poor	Safe Safe	36	WASA-36	139.0608	Poor	Safe Unsafe
10	WASA-10	183.8791	Poor	Safe Unsafe	37	WASA-37	129.2026	Poor	Safe Unsafe
11	WASA-11	40.49298	Excellent	Safe Safe	38	WASA-38	96.02585	Good	Safe Unsafe
12	WASA-12	331.5527	Unsuitable	Safe Safe	39	WASA-39	33.3938	Excellent	Safe Unsafe
13	WASA-13	102.5377	Poor	Safe Unsafe	40	WASA-40	39.93152	Excellent	Safe Safe
14	WASA-14	167.6414	Poor	Safe Unsafe	41	WASA-41	92.11551	Good	Safe Unsafe
15	WASA-15	172.8299	Poor	Safe Unsafe	42	WASA-42	38.94698	Excellent	Safe Unsafe
16	WASA-16	109.1529	Poor	Safe Safe	43	WASA-43	38.81914	Excellent	Safe Unsafe
17	WASA-17	318.497	Unsuitable	Safe Unsafe	44	WASA-44	99.99282	Good	Safe Safe
18	WASA-18	176.6585	Poor	Safe Unsafe	45	WASA-45	36.35929	Excellent	Safe Unsafe
19	WASA-19	127.5504	Poor	Safe Unsafe	46	WASA-46	34.70062	Excellent	Safe Unsafe
20	WASA-20	176.9893	Poor	Safe Unsafe	47	WASA-47	269.4497	Very poor	Safe Unsafe
21	WASA-21	178.5874	Poor	Safe Unsafe	48	WASA-48	34.26264	Excellent	Safe Unsafe
22	WASA-22	315.3953	Unsuitable	Safe Safe	49	WASA-49	151.1592	Poor	Safe Safe
23	WASA-23	203.9375	Very poor	Unsafe Unsafe	50	WASA-50	89.31675	Good	Safe Unsafe
24	WASA-24	177.6634	Poor	Unsafe Unsafe	51	WASA-51	199.8051	Poor	Safe Unsafe
25	WASA-25	169.4641	Poor	Unsafe Unsafe	52	WASA-52	269.712	Very poor	Safe Safe
26	WASA-26	149.1186	Poor	Unsafe Safe	53	WASA-53	326.3757	Unsuitable	Safe Unsafe
27	WASA-27	253.8294	Very poor	Unsafe Safe					

*Filtration plants providing safe/unsafe drinking water.